



# PC UFC Briefing

## September 21-22, 2004

---

# Design and Regulatory Approaches

David Stevens, ARA

# Design Approaches



- Definition of Progressive Collapse:
  - ◇ The commentary in the American Society of Civil Engineers (ASCE) Standard 7-02 "Minimum Design Loads for Buildings and Other Structures" describes progressive collapse as
    - "the spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it."

# Design Approaches



- ASCE 7-02 defines two general approaches for reducing the possibility of progressive collapse:
  - ◇ Indirect Design
  - ◇ Direct Design
- With Indirect Design, resistance to progressive collapse is considered implicitly "through the provision of minimum levels of strength, continuity and ductility".

# Design Approaches



- ASCE 7-02: Direct Design approaches explicitly consider "resistance to progressive collapse during the design process..."
- There are two direct design approaches:
  - 1) the **ALTERNATE PATH (AP) METHOD**, which requires that the structure be capable of bridging over a missing structural element, with the resulting extent of damage being localized,

# Design Approaches



- Direct Design Approaches, cont'd
  - 2) the **SPECIFIC LOCAL RESISTANCE (SLR) METHOD**, which requires that the building, or parts of the building, provide sufficient strength to resist a specific load or threat, i.e., local hardening.
- However, outside DoD and GSA, no quantitative requirements for either direct or indirect design to resist progressive collapse are provided in ASCE 7-02 nor in UBC, IBC, BOCA, ACI, AISC, TMS, etc.



# Design Approaches



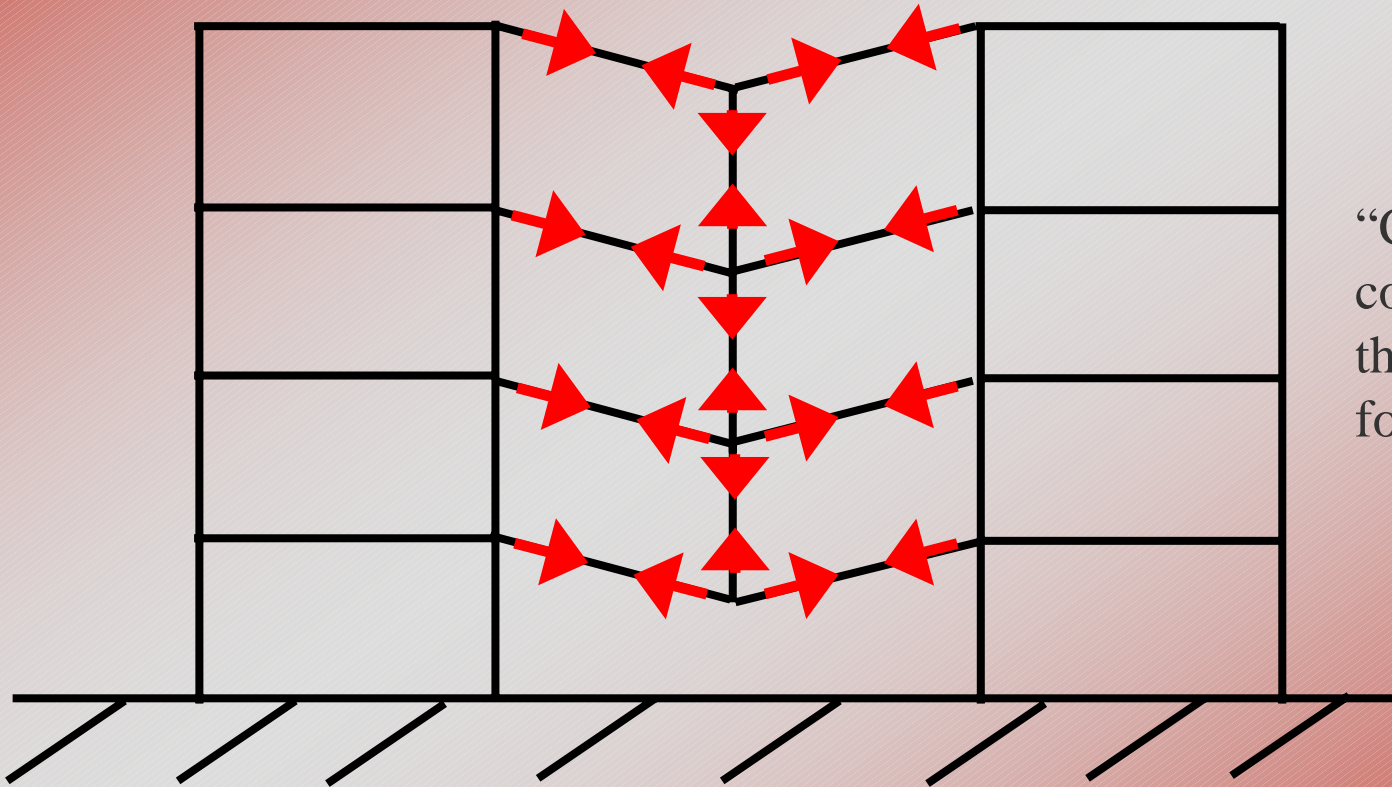
- Initial development of all three methods (Tie Forces, Alternate Path, and Specific Local Resistance) were pioneered by the British in the '60s and '70s
- Their primary motivation was the Ronan Point accident.



# Design Approaches



- Indirect Approach, Tie Forces



“Catenary Action”;  
collapse resisted  
through tensile  
forces

# Design Approaches



- Tie Forces:

- ◇ Tie Forces are purely tensile.
- ◇ Goal is to hold the structure together after an event.
- ◇ The members carrying Tie Forces must have the capacity to transfer the loads from the damaged part of the structure back into the intact portion of the structure.
- ◇ As significant damage can occur locally, the Tie Force members and connections must be able to undergo significant displacements and rotations.

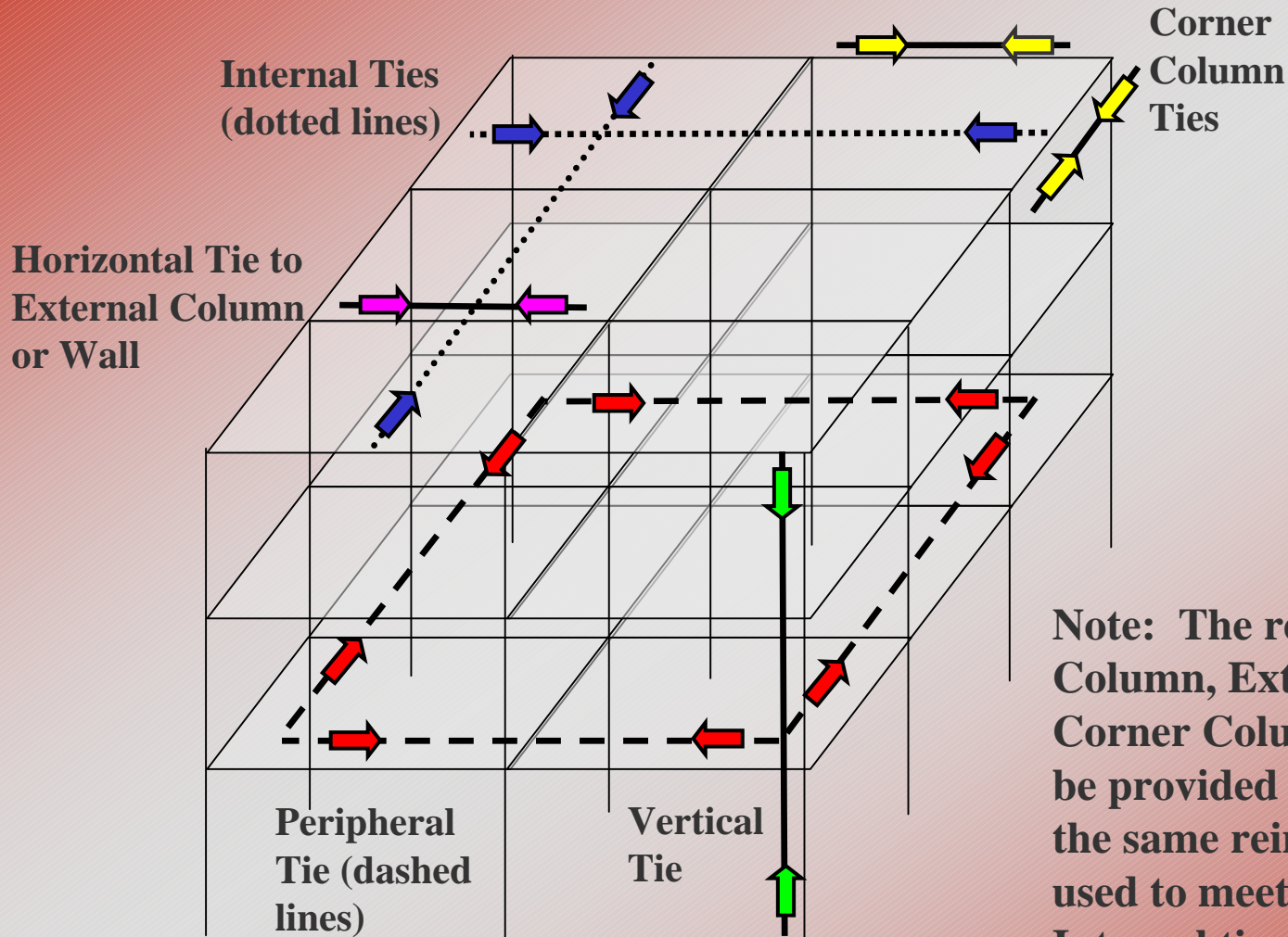


# Design Approaches



- Tie Forces, cont'd:
  - ◇ Tie Forces can be approximately viewed as a “catenary” structural response mode.
  - ◇ To quantify a TF requirement, a code must define:
    - Type of Tie Forces (horizontal or vertical; internal, peripheral, column ties, etc)
    - Location of Tie Forces
    - Magnitude of Tie Forces
  - ◇ British codes do this, although exact reasoning for some requirements are unclear/unknown.

# Design Approaches

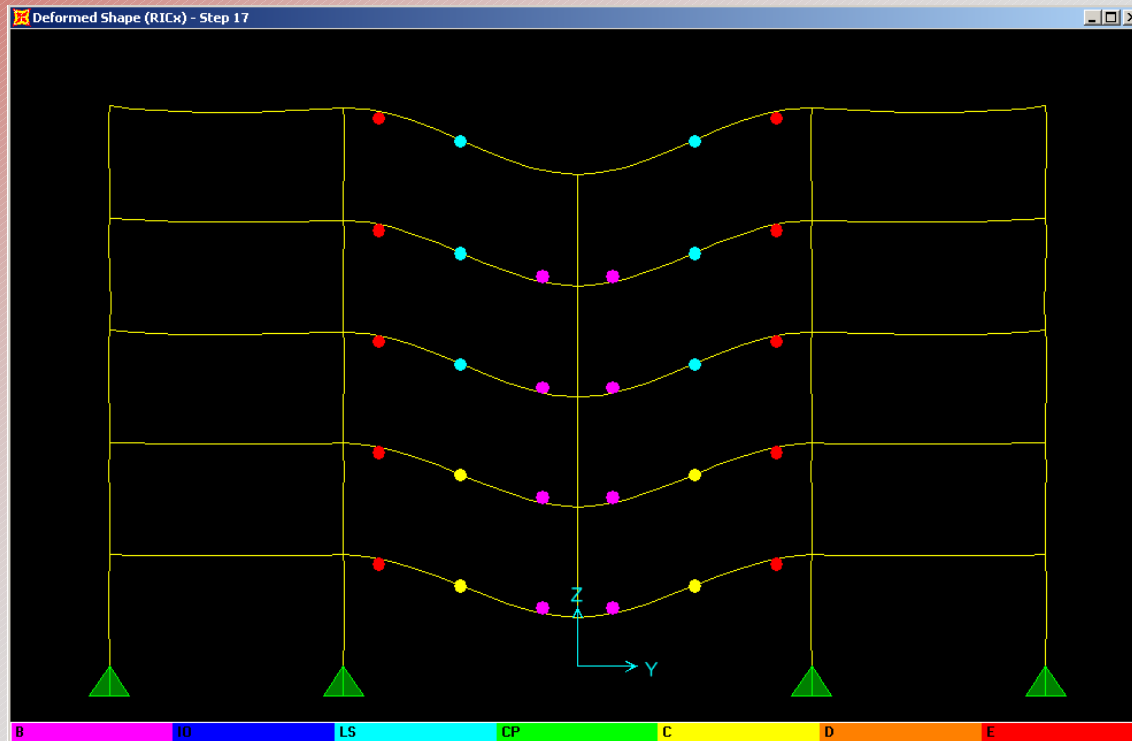


**Note:** The required External Column, External Wall, and Corner Column tie forces may be provided partly or wholly by the same reinforcement that is used to meet the Peripheral or Internal tie requirement.

# Design Approaches



- Direct Approach, Alternate Path

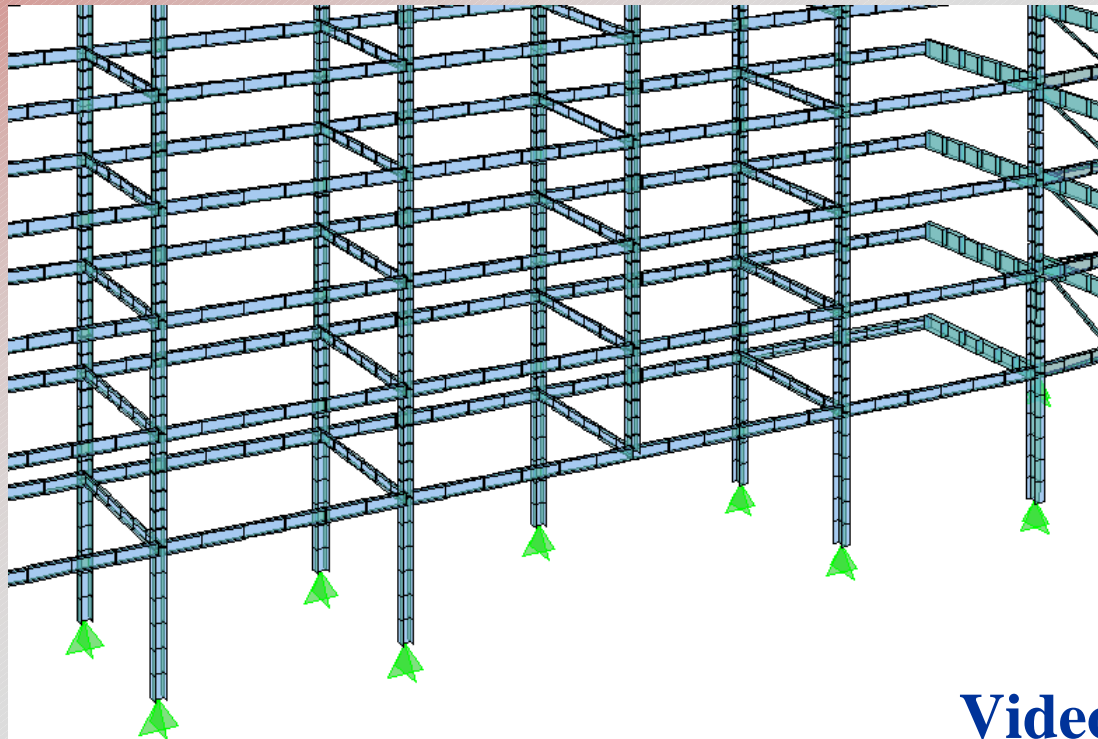


“Flexural Action”;  
collapse resisted by  
bridging across  
locally damaged  
area

# Design Approaches



- Alternate Path, cont'd



**Video provided by  
Myers, Houghton  
& Partners**

# Design Approaches



- Alternate Path, cont'd



**Video provided by  
Myers, Houghton  
& Partners**



# Design Approaches



- Alternate Path, cont'd
  - ◇ Structure must bridge over missing vertical load-bearing element.
  - ◇ Structural response mode is considered as “flexural”, although truss/Vierendeel action can be employed, as well as large roof line beams/spandrels from which the lower levels are hung.

# Design Approaches



- Alternate Path, cont'd
  - ◇ To quantify an AP requirement, a code must define:
    - Type, location, and extend of the removed element.
    - Type, magnitude, and location of the loads.
    - Method(s) for performing the analysis.
    - Criteria for determining if an element yields or fails.
    - Criteria for allowable level of structural damage.

# Design Approaches



- Direct Approach, Specific Local Resistance
  - ◇ In SLR, structural elements are reinforced or hardened to prevent the initial damage that precipitates progressive collapse.
  - ◇ Main difficulty: this is threat-dependent and someone has to define that threat.
  - ◇ British use a 5 psi static pressure as the “threat”.
  - ◇ 5 psi is based on the damage found to a biscuit tin in the apartment that initiated the Ronan Point accident.

# Design Approaches



- Specific Local Resistance, cont'd
  - ◇ SLR is akin to structural hardening
  - ◇ Philosophically, it is not a method for providing general progressive collapse resistance in that it attempts to defeat the initial, local failure.
  - ◇ Main questions:
    - How do you define the threat?
    - How much of the building is designed for the threat?

# Design Approaches



- Quick Summary of the Progressive Collapse UFC
  - ◇ Incorporates both Tie Forces and Alternate Path method, in different combinations, depending upon the level of protection the structure requires.
  - ◇ Specific Local Resistance is not explicitly called out, as this is better handled by the UFCs that deal with structural hardening for new and existing construction
    - **HOWEVER, “additional ductility requirements” for perimeter load-bearing elements are imposed, which, indirectly, increases SLR protection.**



# Design Approaches



- Quick Summary of the PC UFC, cont'd
  - ◇ Load and Resistance Factor Design
    - PC UFC incorporates the LRFD approach as much as possible, for both Tie Forces and Alternate Path.
      - Straightforward for AP.
        - Load cases are defined per ASCE 7-02.
        - Resistance factors can be found in the appropriate design codes.

# Design Approaches



- Quick Summary of the PC UFC, cont'd
  - ◇ Load and Resistance Factor Design, cont'd
    - For Tie Forces, it's not as straightforward:
      - The PC UFC uses the British approach, in which the required tie strength values were developed well before LRFD was.
      - There is some inconsistency in the way required strengths are defined, between reinforced concrete, steel, masonry, etc.
      - These inconsistencies will be pointed out, but won't be addressed/changed until some additional research/engineering work is performed.

# Regulatory Approaches



- Numerous governments and their civilian and military agencies have addressed progressive collapse:
  - US (DoD and GSA)
  - New York City
  - England
  - Canada
  - Sweden
  - “Europe” through the Eurocode (England hasn’t signed on yet)

# Regulatory Approaches



- Essential Reference:
  - ◇ “Comparison of Various Existing Design Standards for the Mitigation of Progressive Collapse in New or Existing Buildings”, Draft Working Document for NIST Meeting on Mitigation of Progressive Collapse, April 24-25, 2003, Washington, DC.
- An abridged version of this report will be published as an appendix to the “Best Practices Guidelines for the Mitigation of Progressive Collapse of Buildings”, in preparation by the National Institute of Standards and Technology.
- Author is Dat Duthinh of NIST.



# DoD Interim Technical Guidance



- Overall approach is Alternate Path Method.
- One primary vertical or one primary horizontal structural element is removed at each floor and the structure checked for progressive collapse.
- Two- or three-dimensional analyses are required, using linear static or nonlinear static computational programs.



# GSA Guidelines



- Analysis and design guidelines are provided separately for Reinforced Concrete and Steel Structures.
- Masonry, wood, and cold-formed steel construction are not considered.
- Alternate Path Method is used exclusively, with linear and nonlinear analyses.
- Only columns or walls on ground floor are removed.

# British Standards



- Overall Approach is Composed of Three Methods for All Structures:
  1. Tying
  2. Bridging (Alternate Path)
  3. Key Element (SLR)
- The PC UFC approach draws heavily upon the British Standards.

# Proposed British Standards



- UK is currently looking at a risk/consequence approach for progressive collapse requirements.
- The proposed changes incorporate the principles of risk analysis such that designers can categorize buildings, taking into account both the risk of the hazard and its consequences.
- Method defines “Risk” and “Consequence” values from which a “Risk Factor” is calculated and the relevant “Risk Category” is determined.

# Proposed British Standards

---



- Proposed Guidance
  - ◇ Risk Category 0 (Exempt)
    - Building Types
      - Traditional 2 and 3 story houses
      - Single story warehouse or storage buildings
    - No special measures required

# Proposed British Standards



- Proposed Guidance, cont'd
  - ◇ Risk Category 1 ( $0.7 < RF \leq 2.0$ )
    - Building Types
      - One family houses  $> 3$  stories
      - Apartments  $\leq 2$  stories
      - Offices
      - Retail  $\leq 2$  stories
    - Horizontal ties required, per existing British Standards



# Proposed British Standards



- Proposed Guidance, cont'd
  - ◇ Risk Category 2 ( $2.0 < RF \leq 4.0$ )
    - Building Types
      - Apartments > 2 stories
      - Hotels  $\leq 3$  stories
      - Educational buildings
      - Hospitals of 1 story
    - Horizontal and vertical ties required, per existing British Standards
    - If horizontal ties can be provided but vertical ties cannot, then bridging is required across the elements without vertical ties (Alternate Path)
    - If it is not possible to bridge, then key element design is required (Specific Load)

# Proposed British Standards



- Proposed Guidance, cont'd
  - ◊ Risk Category 3 (  $RF > 4.0$  )
    - Building Types
      - Hotels  $> 3$  stories
      - Public assembly buildings
      - Hospitals  $> 1$  story
    - “Buildings in this category would require to be assessed to systematically identify the hazards and the risks which may arise.”
    - The hazards should include natural and man-made.
    - “The structural form and concept and any protective measures should then be chosen, identifying load paths and affected areas and taking into account interactions between structural members.”

# Proposed New York City Guidelines



- The New York City Department of Buildings issued the World Trade Center Building Code Task Force report “Draft Progressive Collapse Guidelines” in February 2003.
- General approach very closely follows the British approach.
- Board of Realtors had some concerns with cost implications.
- Status of guidelines and their implementation is unknown.

# Design Approaches

---



**Questions/Comments?**